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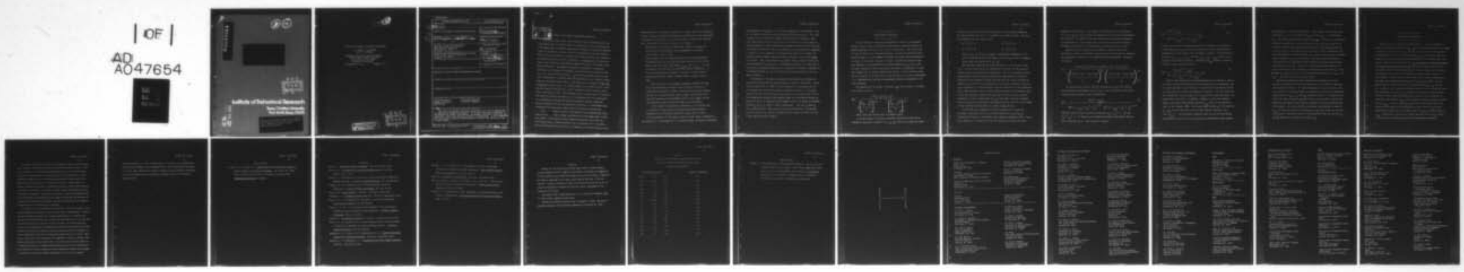

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A Note on the Dynamic Correlation Coefficient

L. R. James, C. W. Hornick,
and R. G. Demaree

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The use of the dynamic correlation coefficient as a test of spuriousness in longitudinal designs was examined. It was shown that given conditions of spuriousness and perfect stationarity, the dynamic correlation coefficient was positively, rather than inversely, related to spuriousness. It was recommended that the dynamic correlation coefficient not be used in the future as a test of spuriousness.

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A Note on the Dynamic Correlation Coefficient

In a recent review, Kenny (1975) noted that the null hypothesis for the cross-lagged panel correlation design is spuriousness. That is, because the cross-lagged panel correlation design does not attempt to include all possible causal or explanatory variables, there is the possibility that the relationships, and causal inferences, provided by the design may have been produced by an uncontrolled third (or more) variable(s). As a _partial_ test for spuriousness in this situation, Vroom (1966) recommended the use of the dynamic correlation coefficient. The dynamic correlation is obtained by correlating difference scores between two variables, each measured at two points in time (i.e., $X_2 - X_1$ is correlated with $Y_2 - Y_1$, where the subscript refers to the time of measurement). Although Vroom noted specifically that "dynamic correlations are inconclusive with respect to the direction of causality and _may also be spurious_" (Vroom, 1966, p. 57; italics added), he nevertheless built a case that the dynamic correlation has a lower likelihood of being spurious than a static correlation (p. 57). The inference based on Vroom's paper is, therefore, that while the dynamic correlation is not a conclusive test for spuriousness, it is nonetheless a partial test and its calculation provides additional salient information for the interpretation of results of a cross-lagged panel correlation study (otherwise, there would be no reason to calculate it).

It has [illegible] common practice in the industrial and organizational psychology literatu[illegible] report dynamic correlations in cross-lagged panel correlation studies. Unfortunately, while authors have typically noted that the cross-lagged panel correlation design is not a conclusive test of causality, several investigators have not been as circumspect as Vroom with respect to the interpretation of the dynamic correlation (cf. Lawler, 1968 for an exception). In fact, a number of authors have inferred or stated directly that the dynamic correlation provided a base, or at the very least a stronger base than the static correlation, for causal inference. For example:

> If the dynamic correlation is significant, there is a strong indication that the two variables under investigation are causally related (Miles, 1975, p. 336).

> These arguments led to a plausible strategy for using longitudinal correlational data to draw inferences about causality in this study: First, check the static correlations, $r_{x_1 y_1}$ and $r_{x_2 y_2}$. If they are positive (or negative), then check the dynamic correlation, ..., if it too is positive (or negative), then infer a causal relation between _x_ and _y_ (Tosi, Hunter, Chesser, Tarter, & Carrol, 1976, p. 278).

> Given a pattern of cross-lagged correlations showing, for example, that subordinate performance causes initiating structure, a large, highly significant, dynamic correlation would strongly support the case for causality (Greene, 1975, p. 189). [It should be noted that Green employed a more meaningful test for cross-lagged correlation differences than is typically found in the literature].

> If the dynamic correlations are significant it is unlikely that an exogenous variable caused any observed relationships between satisfaction and performance (Sheridan & Slocum, 1975, p. 163).

It is the objective of this paper to point out that, given a condition of spuriousness in a cross-lagged panel correlation design, the dynamic correlation will increase, not decrease, as a function of increases in spuriousness. That is, the dynamic correlation covaries positively with spuriousness. Given this condition, not only should the dynamic correlation not be employed to make causal inferences such as the above (i.e., the true state of events might be directly opposite of those suggested by the dynamic correlation), but also that the dynamic correlation is not even a partial test of spuriousness as suggested by Vroom (i.e., in a condition of spuriousness the point is not whether the dynamic correlation may be spurious, rather the point is that it will always be spurious). Thus, even though Vroom provided cautions against overinterpreting the dynamic correlation (i.e., attributing causality), the simple fact of the matter is that any interpretation of the dynamic correlation, regardless of how qualified, might not only be incorrect but directly contrary to the true state of affairs.

The objective of the paper is pursued by first noting the condition of spuriousness graphically and then proceeding to algebraic derivations. As discussed by Kenny (1975, p. 889), the null hypothesis of spuriousness for the cross-lagged panel correlation design is presented in Figure 1. The figure connotes that the "chief alternative explanation of any causal effect" in the cross-lagged panel design is spuriousness, where the relationships between X_t and Y_t are due to an unmeasured third variable and not to a causal relationship between X_t and Y_t (t refers to time of measurement). That is, Z_1 causes X_1 and Y_1 simultaneously, and Z_2 causes X_2 and Y_2 simultaneously. Furthermore, Z_1 is the cause for Z_2, and it is expected that Z changes from time 1 to time 2 (and thus both X and Y change).

Insert Figure 1 about here

If the condition of spuriousness represented in Figure 1 is considered operable, then it would be expected that the dynamic correlation would be of minimal magnitude if in fact it is a test of spuriousness. That this is not the case is shown by the following derivation, in which the conditions represented in Figure 1 and the dynamic correlation are viewed from the perspective of causal, or structural, equations. Because a theoretical perspective has been employed, it was assumed that the random variables $\underline{X}_t$, $\underline{Y}_t$, and $\underline{Z}_t$ were perfectly reliable and that the derivation was based on a population. It was also assumed that the random variables were based on at least interval scales and were measured at the same point in time for each of two waves of measurement (i.e., synchronicity), and that the measurement interval corresponded to the causal interval.

The equation for the dynamic correlation ($\underline{r}_{dc}$) may be viewed, in standard score form, as follows

$$\underline{r}_{dc} = \frac{\Sigma\,[(\underline{x}_2 - \underline{x}_1)\,(\underline{y}_2 - \underline{y}_1)]}{\underline{N}\left[\dfrac{\Sigma(\underline{x}_2 - \underline{x}_1)^2}{\underline{N}}\right]^{1/2}\left[\dfrac{\Sigma(\underline{y}_2 - \underline{y}_1)^2}{\underline{N}}\right]^{1/2}} \qquad (1)$$

where lower-case letters refer to standard scores.

It is now possible to construct structural equations for each of the endogenous (dependent) variables (i.e., $\underline{x}_t$, $\underline{y}_t$) based on the exogenous causal variables $\underline{z}_t$ (correct terminology would require the terms lagged endogenous and lagged exogenous for the $\underline{t}$ = 1 variables [cf. Johnston, 1972]). The structural equations are (in standard form)

$$\underline{x}_1 = \underline{\phi}_1 \underline{z}_1 + \underline{e}_1 \qquad \underline{y}_1 = \underline{\beta}_1 \underline{z}_1 + \underline{e}_2$$

$$\underline{x}_2 = \underline{\phi}_2 \underline{z}_2 + \underline{e}_3 \qquad \underline{y}_2 = \underline{\beta}_2 \underline{z}_2 + \underline{e}_4$$

where $\underline{\phi}_1$, $\underline{\phi}_2$, $\underline{\beta}_1$, and $\underline{\beta}_2$ are causal, or structural, parameters (in the form of standardized regression weights), and the $\underline{e}_{\underline{g}}$ are error or disturbance terms, each distributed $\underline{N}$ (0, $\sigma_{e_{\underline{g}}}^2$).

The following assumptions were made with respect to the structural equations: (a) the causal effects are significant and linear; (b) the exogenous variables are uncorrelated with the disturbance terms in the probability limit (which connotes that the exogenous variables are asymptotically consistent estimators of the endogenous variables and that any other causal variable not included as a predictor in the equations is not causally connected to the exogenous variables); (c) the disturbance terms are uncorrelated in the probability limit, which includes a lack of serial correlation among the disturbance terms; and (d) the endogenous variables are not causes for the exogenous variables. Assumptions (b) and (c) imply that the $\underline{z}_t$ are the major, and only, nonrandom causes for $\underline{x}_t$ and $\underline{y}_t$ at the time of measurement and thus the error terms consist of only "unstable, random shocks" (cf. James & Singh, Note 1).

A final important assumption is that the causal model is perfectly stationary, which means that the structural equations for $\underline{x}_t$ and $\underline{y}_t$ are invariant with respect to time (Kenny, 1975; Pindyck & Rubinfeld, 1976). Given this assumption, it is possible to set the structural parameters for each endogenous variable equal to one another for different waves of measurement (i.e., $\underline{\phi}_1 = \underline{\phi}_2$; $\underline{\beta}_1 = \underline{\beta}_2$), and thus the subscripts for the structural parameters may be deleted. It might be noted that some form of stationarity assumption is required before a cross-lagged panel correlation design can be employed, although the design need not achieve perfect stationarity (Kenny, 1975).

Based on the above assumptions, the dynamic correlation can now be expressed in terms of relationships among the structural equations by replacing each endogenous variable with its respective structural equation. Equation 1 now becomes

$$\underline{r}_{dc} = \frac{\Sigma\left(\left[(\underline{\phi}\,\underline{z}_2 + \underline{e}_3) - (\underline{\phi}\,\underline{z}_1 + \underline{e}_1)\right]\left[(\underline{\beta}\,\underline{z}_2 + \underline{e}_4) - (\underline{\beta}\,\underline{z}_1 + \underline{e}_2)\right]\right)}{\underline{N}\left(\dfrac{\Sigma\left[(\underline{\phi}\,\underline{z}_2 + \underline{e}_3) - (\underline{\phi}\,\underline{z}_1 + \underline{e}_1)\right]^2}{\underline{N}}\right)^{1/2}\left(\dfrac{\Sigma\left[(\underline{\beta}\,\underline{z}_2 + \underline{e}_4) - (\underline{\beta}\,\underline{z}_1 + \underline{e}_2)\right]^2}{\underline{N}}\right)^{1/2}} \qquad (2)$$

By conducting the required algebraic manipulations, where all products with a nonsquared disturbance term are equal to zero in summation, and collecting like terms, equation 2 may be expressed as

$$\underline{r}_{dc} = \frac{2\underline{\phi}\,\underline{\beta}\,(1 - \underline{r}_{\underline{z}_2\underline{z}_1})}{\left[2\underline{\phi}^2(1 - \underline{r}_{\underline{z}_2\underline{z}_1}) + \sigma_{\underline{e}_1}^{\;2} + \sigma_{\underline{e}_3}^{\;2}\right]^{1/2}\left[2\underline{\beta}^2(1 - \underline{r}_{\underline{z}_2\underline{z}_1}) + \sigma_{\underline{e}_2}^{\;2} + \sigma_{\underline{e}_4}^{\;2}\right]^{1/2}} \qquad (3)$$

Equation 3 may be further reduced by noting that $\sigma_{\underline{e}_1}^{\;2} = \sigma_{\underline{e}_3}^{\;2} = 1 - \underline{\phi}^2$, and $\sigma_{\underline{e}_2}^{\;2} = \sigma_{\underline{e}_4}^{\;2} = 1 - \beta^2$ (based on the assumption of perfect stationarity and the use of standard scores). Thus, equation 3 becomes

$$\underline{r}_{dc} = \frac{\underline{\phi}\ \underline{\beta}\ (1 - r_{\underline{z_2 z_1}})}{[(1 - \underline{\phi}^2\ r_{\underline{z_2 z_1}})\ (1 - \underline{\beta}^2\ r_{\underline{z_2 z_1}})]^{1/2}} \tag{4}$$

Finally, the structural parameters $\underline{\phi}$ and $\underline{\beta}$ can be expressed as correlation coefficients $r_{\underline{xz}}$ and $r_{\underline{yz}}$, respectively, because the causal equations are in standardized form and include only one exogenous variable. It should also be noted that $r_{\underline{xz}} = r_{\underline{x_1 z_1}} = r_{\underline{x_2 z_2}}$, and that $r_{\underline{yz}} = r_{\underline{y_1 z_1}} = r_{\underline{y_2 z_2}}$ because of the assumption of perfect stationarity. Furthermore, $r_{\underline{z_2 z_1}}$ is also a structural parameter. Thus, equation 4 becomes

$$\underline{r}_{dc} = \frac{(r_{\underline{xz}}\ r_{\underline{yz}})\ (1 - r_{\underline{z_2 z_1}})}{[(1 - r_{\underline{xz}}^{\ 2}\ r_{\underline{z_2 z_1}})\ (1 - r_{\underline{yz}}^{\ 2}\ r_{\underline{z_2 z_1}})]^{1/2}} \tag{5}$$

Prior to discussing several interesting properties of equation 5, some of the special contingencies employed in its development must be emphasized, and it is most important to note that this is an equation for the dynamic correlation only when these special contingencies are operable. Of first concern are the contingencies that $\underline{z_1}$ is the cause for $\underline{z_2}$ and some change takes place in $\underline{z}$ between time 1 and time 2. In general, a change in $\underline{z}$ over time connotes a change in rank-order among subjects and thus $r_{\underline{z_2 z_1}}$ would not be expected to equal 1.0 (cf. McNemar, 1969). On the other hand, because $\underline{z_1}$ is the cause for $\underline{z_2}$, $r_{\underline{z_2 z_1}}$ would be expected to be of at least moderate magnitude (e.g., $1.00 > r_{\underline{z_2 z_1}} \geq .50$ as arbitrary estimates, where .50 was selected because attributing more than 75% of the $\underline{z_2}$ variance to random shocks rather strains the credibility of causal interpretation). Thus, we have ruled out the conditions where $r_{z_2z_1} = 1.0$, in which case $r_{dc} = 0$, and $r_{z_2z_1} < .50$ (including $r_{z_2z_1} = 0$, where r_{dc} would then be equal to $r_{xz}\ r_{yz}$). Second, the contingencies employed to construct the structural equations for x_t and y_t presumed that a condition of spuriousness did in fact exist, where z_1 was the only cause for x_1 and y_1, and z_2 was the only cause for x_2 and y_2. These contingencies rule out the possibility of "self-causation" (e.g., x_1 is a cause for x_2) and "cross-lagged causation" (e.g., x_1 is a cause for y_2), and provided the basis for stipulating that the disturbance terms contained only random shocks and were uncorrelated in the limit. Finally, in conjunction with the assumption of perfect stationarity, the contingency of spuriousness connotes that r_{xz} (or ϕ) and that r_{yz} (or β) should be of at least moderate magnitude (e.g., $r_{xz} \geq .50$, $r_{yz} \geq .50$, which are again arbitrary limits).

The above contingencies simply represent the assumptions that were required to formulate the structural equations for the condition of spuriousness presented in Figure 1. If these assumptions are treated as given, then it is possible to view the behavior of the dynamic correlation for arbitrarily chosen values of $r_{z_2z_1}$, r_{xz}, and r_{yz}, as shown in Table 1. In preparing this table, the values of r_{xz} and r_{yz} were set equal to one another in most cases simply for computational ease; however, examples of differing magnitudes were also included. Also, only positive correlations were addressed; a negative $r_{z_2z_1}$ is extremely unlikely, a negative r_{xz} or r_{yz} would change only the sign of r_{dc} but not the general thrust of the conclusions below, and negative r_{xz} and r_{yz} would have no effect on the sign of r_{dc}.

Insert Table 1 about here

Three points are of interest in viewing Table 1. First, a condition of perfect spuriousness, indicated by $r_{xz} = r_{yz} = 1.00$, will always lead to a dynamic correlation of 1.00 as long as $r_{z_2z_1} \neq 1.00$. The rationale for this result is straightforward; one is in essence correlating $z_2 - z_1$ with itself (this also clarifies why at least some change in rank-order must occur between time 1 and time 2). Second, for a given level of $r_{z_2z_1}$, the dynamic correlation increases as the degree of spuriousness increases. Thus, the dynamic correlation is positively related to spuriousness, where it has been assumed that an inverse relationship existed (i.e., a high dynamic correlation implied a lack of spuriousness). The rationale for this result is also rather straightforward. The higher the relationship between z_t and both x_t and y_t (where all t are equal), then the higher will be the correlations between $z_2 - z_1$ and both $x_2 - x_1$ and $y_2 - y_1$. As these correlations increase, then so should the correlation between $x_2 - x_1$ and $y_2 - y_1$ because of the common, underlying causal variable. Third, the relationship between the degree of spuriousness, as reflected by the product $r_{xz}r_{yz}$, and the dynamic correlation varies as a function of $r_{z_2z_1}$. That is, although r_{dc} will attain high values only in the presence of high degrees of spuriousness, the high values of r_{dc} will be achieved more quickly (i.e., for lower values of $r_{xz}r_{yz}$) for lower values of $r_{z_2z_1}$. Nevertheless, this does not detract from the fact that r_{dc} is positively related to spuriousness given the aforementioned conditions.

It should be noted that several of the assumptions made in the derivation (e.g., perfect reliability) would not be met in most empirical studies. Moreover, a number of the assumptions associated with the use of the structural equations, including perfect stationarity rather than proportional or quasi-stationarity (Kenny, 1975) and uncorrelated disturbance terms, would not be mandatory for the computation of a dynamic correlation. Nonetheless, the dynamic correlation does imply an underlying structural equation model because it attempts to attribute, or at least to infer, causal relationships (but not direction) to variables. Furthermore, the extent to which the assumptions are met would influence the magnitude of the dynamic correlation, and increase the probability of an incorrect conclusion regarding spuriousness if the original interpretation of the statistic were employed.

In conclusion, two recommendations are offered. First, the dynamic correlation should not be employed as even a partial test of spuriousness. Second, the most meaningful procedure for studying spuriousness is to identify the omitted causal variables that are creating the spuriousness and to include such variables in analyses, or provide controls for them. The latter procedure, control, can be achieved by randomization and experimentation, while the former procedure, inclusion in analysis, can best be achieved from the standpoint of causal explanation by the use of structural equation models (cf. Christ, 1966; Duncan, 1975; Heise, 1975; Johnston, 1972; Namboodiri, Carter, & Blalock, 1975; Pindyck & Rubinfeld, 1976; Theil, 1971). Structural equation models might be of particular interest to applied psychologists because they are applicable to data obtained in natural settings and can be employed to address such problems as reciprocal causation and random measurement error, as well as dynamic interrelationships (cf. James & Singh, Note 1). In effect, it is perhaps time to movè from intermediary causal designs such as cross-lagged panel correlation (cf. Kenny, 1975) and proceed to think in terms of the more holistic theoretical systems, and competing causal hypotheses, required by the use of structural equation models.

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Table 1

Magnitude of the Dynamic Correlation for Selected Values of Structural Parameters Representing Causation and Spuriousness

Structural Parameters			Dynamic Correlation
$r_{z_2z_1}$	r_{xz}	r_{yz}	r_{dc}
.90	1.00	1.00	1.00
.90	.95	.95	.48
.90	.75	.75	.11
.90	.50	.50	.03
.90	.75	.50	.06
.75	1.00	1.00	1.00
.75	.95	.95	.70
.75	.75	.75	.24
.75	.50	.50	.08
.75	.75	.50	.14
.50	1.00	1.00	1.00
.50	.95	.95	.82
.50	.75	.75	.39
.50	.50	.50	.14
.50	.75	.50	.24

Figure Captions

Figure 1. Cross-lagged panel correlation null hypothesis. (_X_, _Y_, and _Z_ are variables and 1 and 2 are times) (From "Cross-Lagged Panel Correlation: A Test for Spuriousness" by D. A. Kenny, _Psychological Bulletin_, 1975, _82_, 887-903. Copright 1974 by the American Psychological Association. Reprinted by permission).

$$
\begin{tikzcd}
X_1 & X_2 \\
Z_1 \arrow[u] \arrow[d] \arrow[r] & Z_2 \arrow[u] \arrow[d] \\
Y_1 & Y_2
\end{tikzcd}
$$

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